Appendix B: A Representative System in Portland, OR

CTC studied a large metropolitan system that is technologically typical of HFC cable architectures around the United States and examined its capabilities from the point of view of open access. To this end, CTC studied the AT&T Broadband cable system in Portland, Oregon.

With its standard HFC architecture, the Portland AT&T system is typical of the majority of current American cable systems. No form of access by multiple ISPs has been offered over this system. However, there is no technical reason why, properly equipped, that system cannot offer either a separate-channel or a policy-based router plan (discussed in Section III), provided that AT&T deploys the necessary equipment and works in cooperation with ISPs.

A CTC engineer attempted to meet with AT&T staff and to tour the cable system in October 2001, but AT&T refused to meet with CTC. As an alternative, CTC obtained extensive information regarding the system from David C. Olson, the Director of the Mount Hood Cable Regulatory Commission, the regulatory body overseeing the cable system that encompasses Portland. Mr. Olson conducted a follow-up discussion with AT&T staff in December 2001 and obtained further information CTC requested for the Report.[42]

I. Network Background and Architecture

The Portland cable system was constructed as a branch and tree system in the late 1970s and early 1980s for one-way entertainment services. The system was initially operated by Paragon/Time Warner and TCI in the East Multnomah County and City of Portland franchise areas. AT&T took over the whole system in early 1999 as part of its purchase of TCI. As a condition of the transfer of the cable system to AT&T, the City attempted to require that it open its system to multiple ISPs. AT&T challenged this decision in the courts, and the requirement was eventually voided.

Later in 1999, AT&T began an upgrade of its systems to HFC and has completed upgrades throughout the City. AT&T was able to address the limitations of the original network by adding fiber optic plant lashed to its existing cable, and upgrading its headend and cable plant electronics for cable modem and telephone services. The network has backup power in the cable plant and a redundantly-routed fiber optic backbone ring.

With respect to service issues, Olson reported that Portland customers have significant problems with AT&T, especially poor response time for telephone calls. The City had fined AT&T $180,000 as of the end of 2000 for not answering the telephone in accordance with FCC and City standards.

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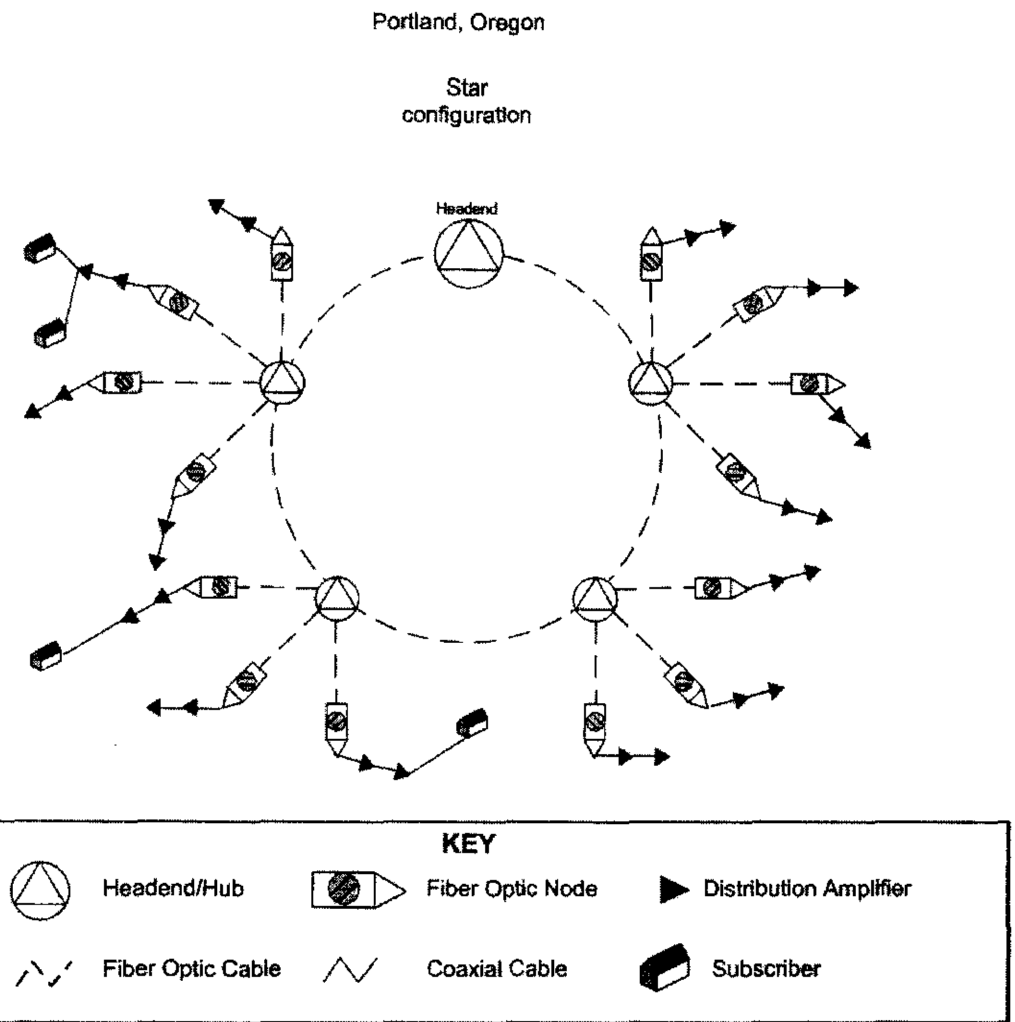
[42] CTC wishes to acknowledge and thank Mr. Olson for his tireless efforts to obtain information for this Report. CTC's analysis of the Portland AT&T system would have been impossible without Mr. Olson's assistance.

AT&T's broadband network in Portland has the following features:

- Fiber optic backbone between headend and six hubs.
- 1751.75 miles of cable plant.
- Star configuration of fiber optics between hubs nodes serving between 650 and 675 homes.
- Six fibers from hubs to each residential node.
- 750 MHz capacity, coaxial cable plant, two-way activated.
- Two to four-hour battery backup at each power supply diesel generators at headend and hubs.
- Video lineup originated from headend.
- SONET and Gigabit Ethernet fiber optic transport backbone between hubs.
- Electronic status monitoring of hubs.
- Electronic status monitoring of headend, hubs, power supplies, nodes, amplifiers, and customer premises to the parts of the system where cable TV, broadband Internet, and cable telephony are all offered.
- Where status monitoring is active, it is monitored 24 hours a day, seven days a week, 365 days a year.
- Seventy-five analog video channels.
- 180 digital video channels.
- Eight public, educational, and government (PEG) channels;
- Scientific Atlanta and GI/Motorola set-top converters for analog subscribers are available for purchase.
- GI/Motorola set-top converters for digital subscribers.
- Internet and digital video available.

Figure B-1 shows the main fiber architecture of the system. In Portland, AT&T uses a star configuration for distributing fiber from the hubs to neighborhood nodes, with a single connection between each node and its hub.

Figure B-1: Portland Network Architecture



II. Cable Modem Network

Cable modem services have been migrated from Excite@Home to AT&T WorldNet on AT&T Broadband, which handles all aspects of customer installation, provisioning, and service as the single ISP in the area. Excite@Home served as the sole ISP on the system until AT&T migrated users to AT&T WorldNet following the bankruptcy of Excite@Home. AT&T WorldNet is currently the only ISP offered on this system. As of this writing, there are no plans to offer competing ISPs.

The AT&T cable modem network has the following characteristics:

- DOCSIS 1.0 compliant CMTS and cable modems.
- Local cache stores recently requested content.
- All CMTS equipment located at the headend.

AT&T has placed some restrictions on the use of its cable modem network. These include:

- No capacity guarantees.
- Customers are restricted to maximum 1.5 Mpbs downstream and 128 kbps upstream speed.
- Limitations on subscribers hosting servers, operating VPNs, and conferencing software.
- Customers are allowed, with limitations, to connect multiple PCs and home networks to their cable modem.

III. The Portland I-Net

The agreement between the City of Portland and AT&T Broadband requires the cable operator to pay a five percent franchise fee, three percent PEG capital grant, and all applicable taxes. Additionally, AT&T Broadband is required to construct fiber optic and coaxial cable plant to designated facilities at incremental cost.

The Portland I-Net consists of high-capacity sites and low-capacity sites. High-capacity sites have capacities of 180 MHz both upstream and downstream between each site and its corresponding fiber node. Low-capacity I-Net sites have a minimum of eight MHz upstream and 12 MHz downstream capacity. The low-capacity I-Net system has the following features:

- One four-slot CMTS at the headend connected to all the I-Net sites.
- CMTS only routes data within the city network, effectively forming a LAN for the City I-Net sites.
- Six hubs: five in East Portland, one in West Portland.
- Six fibers between sites and nodes.
- Two fibers to an additional node at the site, with a coaxial drop to the site, and four dark fibers directly to the site.
- A total of 290 nodes.
- Six fibers between hubs and headend.
- Video can be originated from any I-Net site.
- Twenty percent of sites share a node with another site.

As of December 4, 2000, 61 sites were in operation over the I-Net. Video applications have been supported successfully by the low-capacity I-Net, but data and Internet usage has had bandwidth problems. All Internet traffic from every site in the City I-Net currently travels through one cable modem to a router in a central Portland building, creating a substantial bottleneck. Proposed solutions to this problem include connecting fiber from the I-Net CMTS directly to the Internet router. A proposal has also been made to connect the AT&T I-Net to the IRNE Network, a fiber network already constructed by the City of Portland. The IRNE Network contains a backbone in Portland that could be extended by the I-Net to distribute connectivity to all I-Net sites.

Appendix C: Technical Description of Branch and Tree Architecture

"Branch and tree" coaxial cable topology refers to the architecture of cable systems that have typically not been upgraded since 1995. These systems are also known as "legacy" systems because their architecture dates from the earliest days of cable in the 1950s and 1960s.[43]

I. Technical Description of Branch and Tree Architecture

Branch and tree systems utilize dated technology that reflects the origin of cable television as a one-way entertainment medium with no status monitoring systems or architectural redundancy. Early cable television systems started as centralized antennas on hills that received over-the-air television signals and transmitted them by cable to homes that could not receive over-the-air signals. In later years, cable systems added additional signals to their offerings by receiving programming over satellite dishes. In this way, cable became a transmission medium for superstations, national news, sports, and movies channels as well as for the original local broadcast stations. Cable was able to offer more programming alternatives and better quality than over-the-air television.

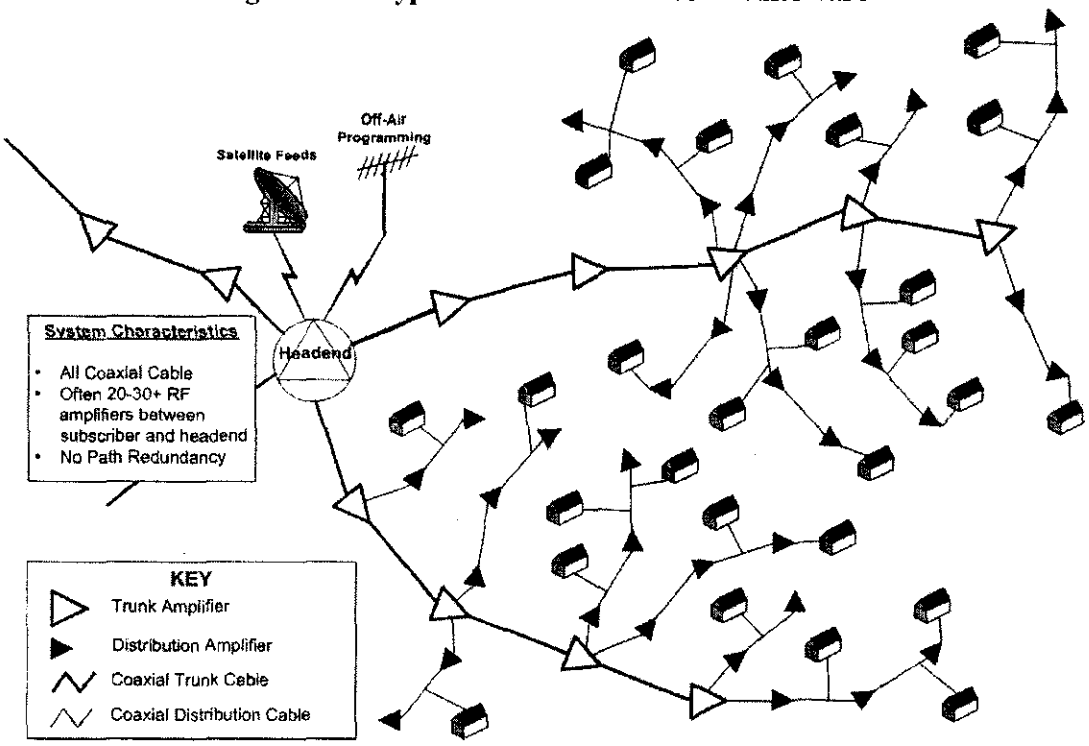
Architecture

The headend is at the center of a branch and tree cable system. It serves as the control center and reception point for all of the programming materials carried on the system. The trunk cables transport television signals from the headend to the most distant points in the franchise service area.

A typical branch and tree system is diagrammed in Figure C-1.

[43] After the most recent round of system upgrades in the late 1990s and early 2000s, most urban and suburban systems have been upgraded to HFC. Branch and Tree systems are found primarily in rural and less populated areas.

Figure C-1: Typical Branch and Tree Architecture



In a branch and tree system, the cable headend receives signals over two general types of antennas: off-air television antennas for local channels and satellite antennas (dishes) for long distance signals. For optimal signal reception, the antennas and headend are often located on a hilltop or other raised land area. Off-air antennas, which receive 55 to 890 MHz signals[44], are located on towers and aimed at television broadcast stations. Satellite dishes, which receive signals in the C band (3.7 to 4.2 GHz) and Ku band (11.7 to 12.2 GHz)[45], are aligned with their transmitting satellites in geosynchronous orbit.

Local television stations sometimes deliver their programs directly to the headend over fiber optic cable to bypass the reception and processing issues associated with radio frequency (RF) transmissions.

Branch and tree systems use coaxial cable to deliver these signals to subscribers. A signal traveling through coaxial cable must be regenerated every one-third to one-half mile by an amplifier. The amplifier serves to boost the signal, but also introduces noise and distortion into the signal and is a potential point of failure in the system.

The size of the area served by a single coaxial cable system is limited by the maximum number of trunk amplifiers that can be connected in series, or "cascaded," and still be

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[44] Bartlett, Eugene R., Cable Television Technology & Operations, New York: McGraw-Hill, Inc., 1990, p.230.

[45] Ciciora, Walter et al., Modern Cable Television Technology, San Francisco: Morgan Kaufmann Publishers, Inc., 1999, p.337.

capable of providing a satisfactory signal to the most distant subscriber. As is illustrated in Figure C-1, the trunking network functions as the backbone for the cable system. Typical systems have trunk cable runs comprised of between 15 and 40 amplifiers in series from the headend to the most distant subscriber.

The distribution system, which passes by each subscriber residence, connects the home subscriber to the trunk cable. Scrambled signals can be recovered either by set-top converters at subscriber homes or by traps on the coaxial line which either block or pass certain channels.

Locations nearest the cable system headend receive the best signal quality because traditional coaxial cable architecture requires a long cascade, a large number of amplifiers connected in series. As the signals travel through the amplifier chain and coaxial cable, a gradual degradation of signal quality occurs. Signal quality will decrease to the point where it becomes unacceptable to the subscriber if there is a sufficiently long amplifier cascade between the subscriber and headend.

In order to service larger areas, cable operators must construct multiple headends or hubs or must devise special interconnection networks for connecting the systems. Multi-channel microwave links, "super-trunk" cable, and point-to-point fiber optic links are generally the most common technologies used for interconnection.

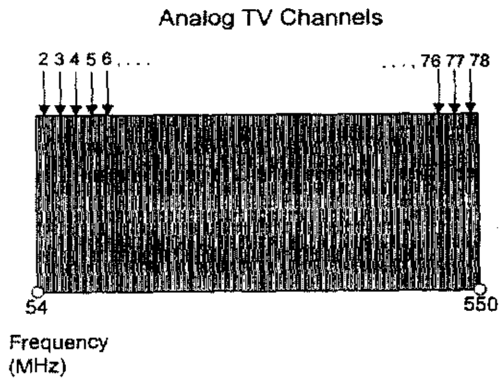
Bandwidth and Frequencies

Branch and tree systems have only sufficient channel capacity to support one-way, analog television signals. They typically range from 330 to 550 MHz, or 40 to 75 television channels. Figure C-2 illustrates how frequencies are allocated for cable television systems and how branch and tree system capacity supports only analog television channels in contrast to the categories of systems discussed below, which can also support digital TV and interactive applications.[46]

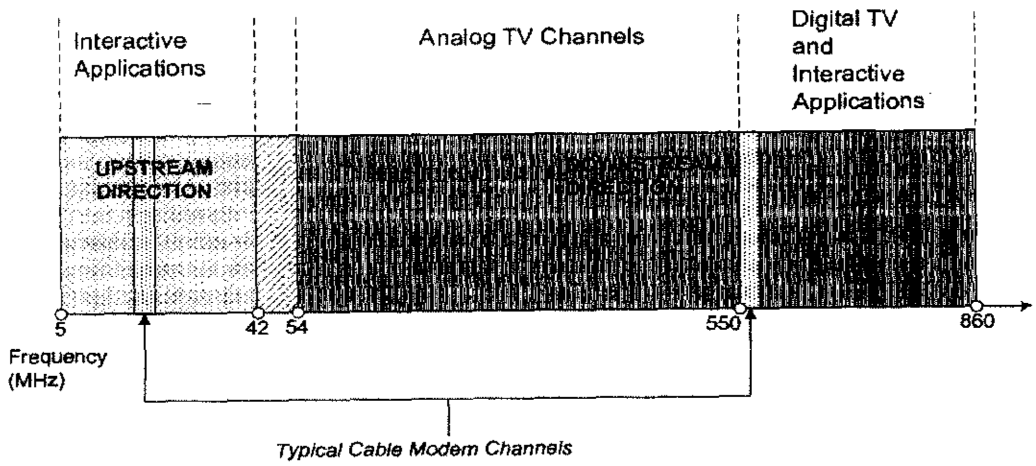
[46] Communications and Engineering Design (CED) 2001-2002 Frequency Allocation Chart.

Figure C-2: Typical Broadband Subscriber Frequency Allocation

Branch and Tree System Capacity



HFC and FTTC System Capacity



Headend Operations

After they are received from the antenna tower, off-air television transmissions pass through a series of signal processors that prepare the signals for distribution from the headend through the cable. An amplifier increases the strength of the received signal so that it is suitable for processing. RF signal processors or modulators convert off-air antenna signals into those suitable for cable broadcasting.

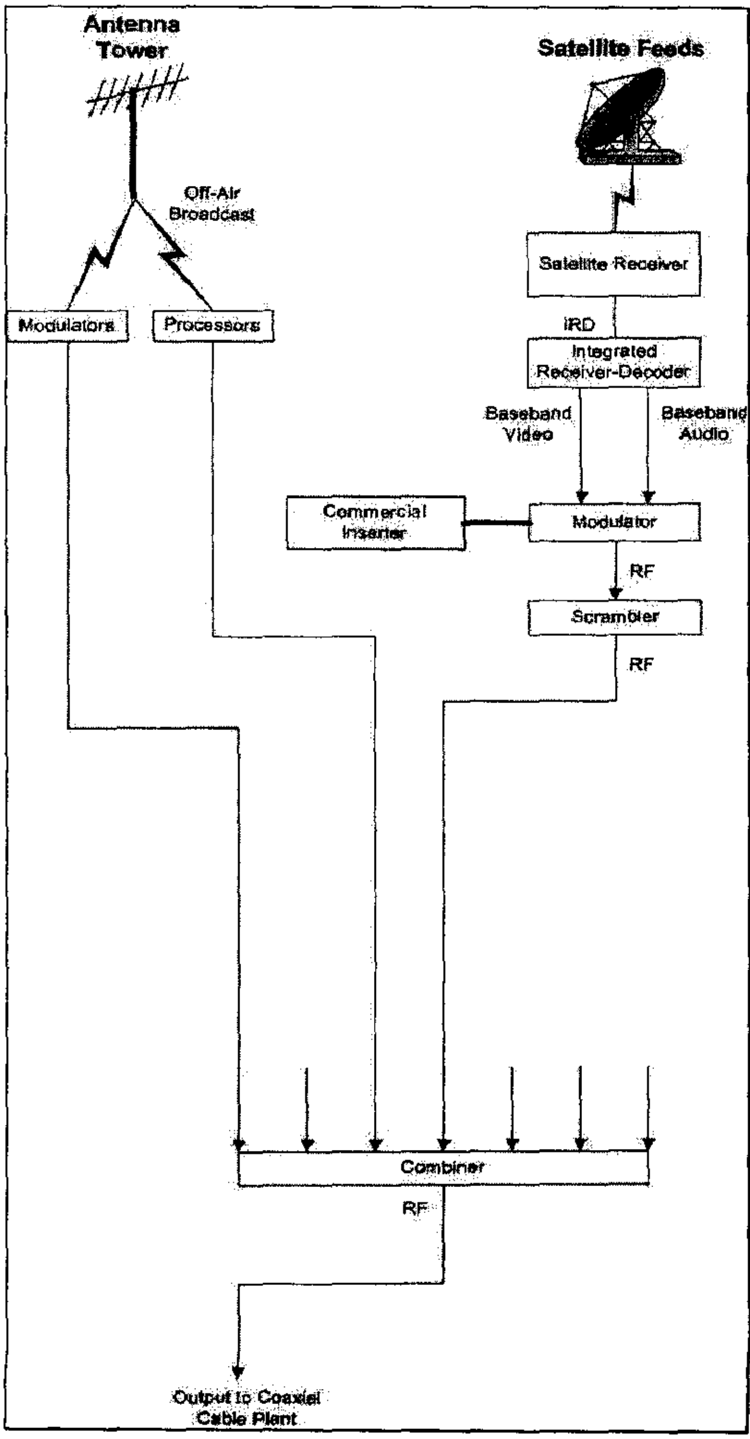
Signals from satellite transmissions undergo a more involved process. After amplification, the signal frequency is downconverted to a lower spectrum (usually 950 – 1450 MHz) because signal loss at the C and Ku satellite bands is too high for transmission through the cable to the headend.[47] The signal is then sent from the dish to the satellite receiver in the headend building where it is further amplified, downconverted, demodulated to baseband frequency, and filtered. Filtering removes noise from adjacent channels and isolates each signal.

As most satellite signals are scrambled to avoid signal theft, a descrambler is used on the incoming transmission. An integrated receiver-decoder (IRD) often performs both receiving and descrambling operations in newer headends.[48] A modulator converts the processed satellite signals to the proper RF channel frequencies for coaxial television reception. Commercial advertisements can be inserted into predesignated ad spots in the programming. Premium and pay-per-view channels are scrambled. A combiner links the individual modulator and processor outputs to the cable system.

Figure C-3 illustrates typical signal flow of a branch and tree headend.

[47] Ciciora, et al., Modern Cable Television Technology, p.275.
[48] Ibid., p.360.

Figure C- 3: Branch and Tree Headend



II. Technical Limitations of Branch and Tree Architecture

There are significant technical limitations with this architecture. The large physical size of the network results in a large number of potential points of failures. All subscribers beyond a failure point experience system outages if a failure occurs in a trunk amplifier located between the headend and the end of the network. In a large cable system, an individual trunk cable might be part of a link that serves tens of thousands of subscribers. A failure at or near the headend can result in a substantial number of subscribers experiencing an outage.

Maintaining the system is an expensive and extensive task, because every trunk amplifier must be checked and adjusted relative to the other amplifiers, a challenge comparable to tuning a group of musical instruments.

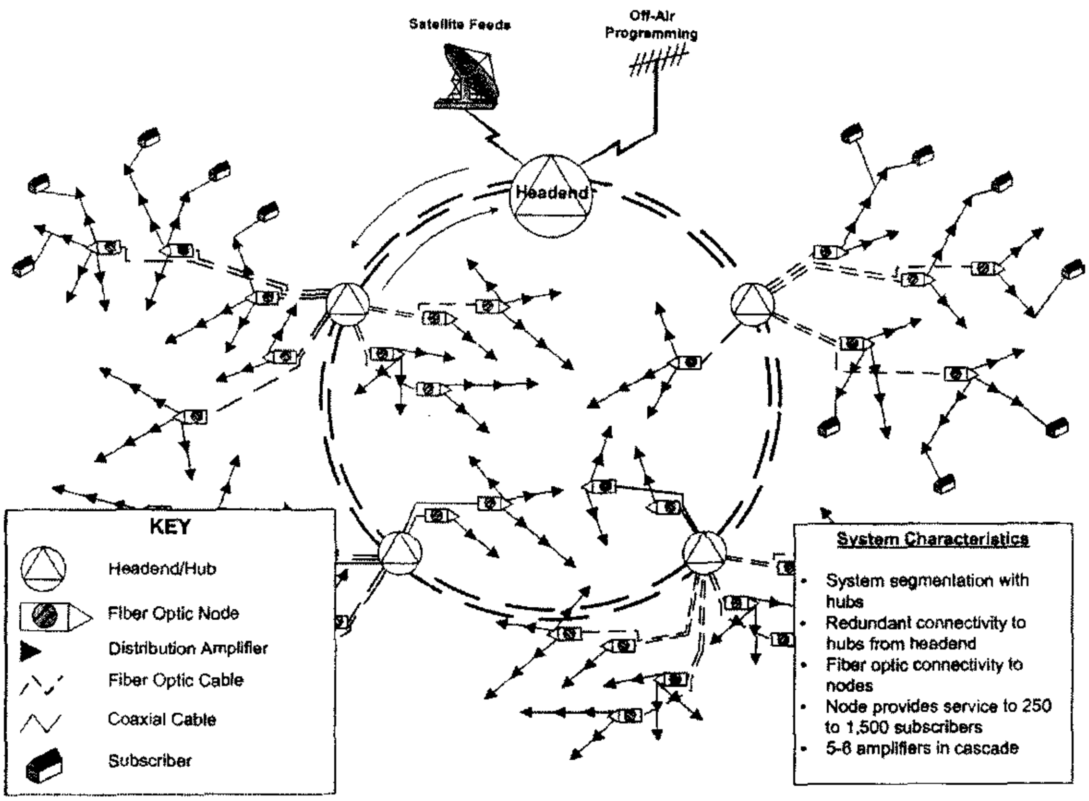
Branch and Tree Architecture Precludes Two-Way Service and Open Access

All-coaxial systems cannot offer two-way services other than rudimentary pay-per-view and telemetry. Two-way operation is precluded by the large amount of system noise in the upstream direction and by the lack of fiber optics and, therefore, of significant capacity. A branch and tree system is based on one trunk. This is in contrast to more recent architectures, in which the system is segmented (essentially, multiple trunks are created by construction of neighborhood fiber optic nodes that translate and boost the signal) to enable each node to reuse channels and thereby multiply capacity for cable modem users.

Appendix D: Technical Description of Hybrid Fiber/Coaxial Architecture

Since the mid-1990s, most American cable networks have incorporated fiber optic technology. These systems use fiber optic cable to link the headend to neighborhood coaxial cable in an architecture called Hybrid Fiber/coaxial (HFC). In the neighborhoods, the traditional coaxial cable distribution remains but with upgrades to enable two-way operation. Figure D-1 illustrates HFC architecture.

Figure D-1: Modern Hybrid Fiber/Coaxial Architecture



I. Technical Description of HFC Architecture

Generally, the evolution of cable networks from the branch and tree configuration to modern HFC networks has entailed construction of fiber optics from the headend to intermediate "hubs" and then eventually to "nodes" in each neighborhood. The nodes contain active devices that convert the fiber optic signals to RF signals for delivery over existing coaxial cable. This architecture has enabled the provision of two-way services and has greatly increased the reliability and quality of the signals offered over the cable system.

Hub and Node Segmentation

In an HFC system, signals leave the headend through laser transmitters that convert signals from RF format into light. Narrowcast lasers send signals bound for specific nodes, and higher power broadcast lasers transmit video signals that are shared by all nodes. Broadcast laser transmissions typically transmit the video programming to all nodes and are optically split along the network path as needed. Fiber optic signals are transmitted by way of hubs and are then received by nodes that convert the signal into RF for coaxial distribution to subscribers. Nodes also contain laser transmitters that send upstream data originating from subscribers back to laser receivers in the headend.

Distribution facilities, known as "hubs," interconnect fibers to the neighborhood node areas and are intermediate between headend and node in a metropolitan area system. The hubs vary in size depending on the design philosophy or complexity of the network; however, they are usually stand-alone facilities with continuous backup battery power. The hub facilities receive their signals from the headend, usually by two discrete transmission paths to ensure that loss of an interconnection cable at one location will not create a single point of failure.

Hubs connect over fiber optic cable to neighborhood nodes, where the fiber interfaces with the coaxial distribution cable. The area served by a neighborhood node is referred to as the node area. Systems are typically designed with node areas that support between 100 and 2,500 residential dwelling units. Smaller node size allows for higher two-way capacity, along with greater system reliability.

The number of amplifiers between the headend and subscriber is reduced to less than eight in an HFC system. The shorter cascade lowers the signal degradation and reduces the number of potential failure points. An HFC system might typically have a capacity of 750 to 860 MHz, used to support a variety of analog and digital video services, two-way interactive data, and telephony.

HFC systems enable the reuse of system capacity for different neighborhood nodes. In other words, the segmentation of the system into separate nodes enables narrowcasting to individual node service areas, much as if each area were a different cable system. This segmentation enables the system to have adequate two-way capacity for telephone, Internet service, and video-on-demand. With increased network capabilities comes increased flexibility as well as technical complexity, since different combinations of multiple services are available.

HFC architecture enables a system simultaneously to broadcast cable channels systemwide and to narrowcast services that are specific to a neighborhood node. Transmissions from data, telephony, and pay-per-view can be sent to individual users based on their service node.

Bandwidth

Figure C-2 of Appendix C illustrates the allocation of bandwidth in a typical modern cable system. In the forward direction (from the headend to the subscriber) the available bandwidth could be in excess of 800 MHz. In the return path, information sent from the subscriber to the headend, the bandwidth is limited to a narrower range. As shown in Figure C-2, the spectrum from 5 to 40 MHz is available for transmissions back to the headend, for a total effective bandwidth of less than 35 MHz.[49] This asymmetry exists because cable was originally designed as a one-way technology maximizing bandwidth to the consumer.

Interactive services include pay-per-view and video-on-demand ordering, cable modem network status monitoring, and telephony. If services are to remain in operation during power outages at the subscriber's home, additional power redundancy must be built into the HFC network. The redundancy may be in the form of power through the network, as is done over standard telephone networks, or power through a battery pack at the subscriber's home.

The size of the node area is a critical performance parameter because all of the bandwidth for interactive services must be shared among the users connected to the node. For example, a node serving 500 homes with a cable modem penetration of fifty percent might need to service up to 250 users simultaneously. In contrast, a smaller node serving 150 homes with the same penetration level would only be required to service 75 homes simultaneously, essentially providing three and one-half times as much usable bandwidth for each subscriber.

Headend

HFC system headends have similar receiving antennas and processing equipment to branch and tree systems, but with additional equipment to accommodate such two-way services as high speed Internet and telephony.

Figure D-2 illustrates a typical HFC headend.

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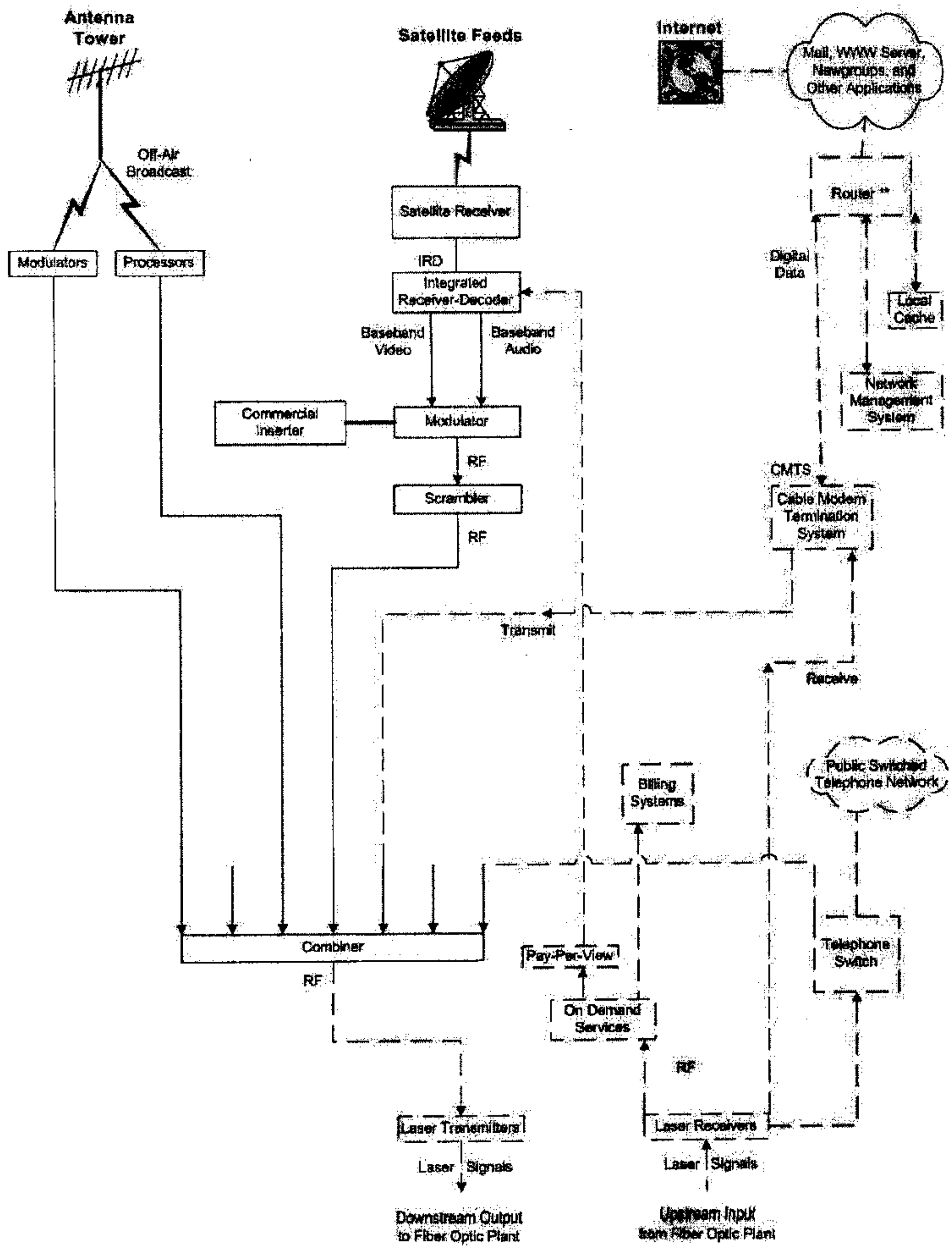
[49] Ibid., p.577.

Figure D-2: Hybrid Fiber/Coaxial Headend*



*Dashed lines indicate components and services not present in branch and tree systems.
**In a PBR-based open access scenario, this router would be a policy-based router with direct connections to multiple ISPs and the Internet.

Redundancy

HFC system headends include system redundancy that was not a priority in branch and tree systems. Redundancy typically includes backup power and redundant HVAC. Redundancy also includes failsafe communications technologies such as SONET backbone rings and data and telephone equipment with redundant power supplies, chassis, and modules. Headend facilities are equipped with battery uninterruptible power supplies and diesel or natural gas generators that continuously power the headend in the event of a power failure. Status monitoring devices in the system headend monitor the signal and power systems in the cable network. Monitoring equipment can then notify maintenance staff of any problems that need attention before the problems affect subscribers.

Staffing Needs

Introduction of advanced cable technologies necessitates a corresponding upgrade in the skills of system staff. A 24-hour staff presence is needed in the headend or data center to detect and troubleshoot problems. Other parts of the network should be configured to alert staff of problems.

Repair personnel must also have expertise in fiber splicing. Customer service and installation staff must be versed in computer hardware and software. Installing cable modems at subscriber homes involves knowing how to install PC peripherals, dealing with a wide variety of customers and their computers, and being able to recognize user hardware and software which may or may not be compatible with the components to be installed. Procedures must in place to escalate problems to regional or national staff or to vendor support in the event that these issues cannot be resolved by system staff.

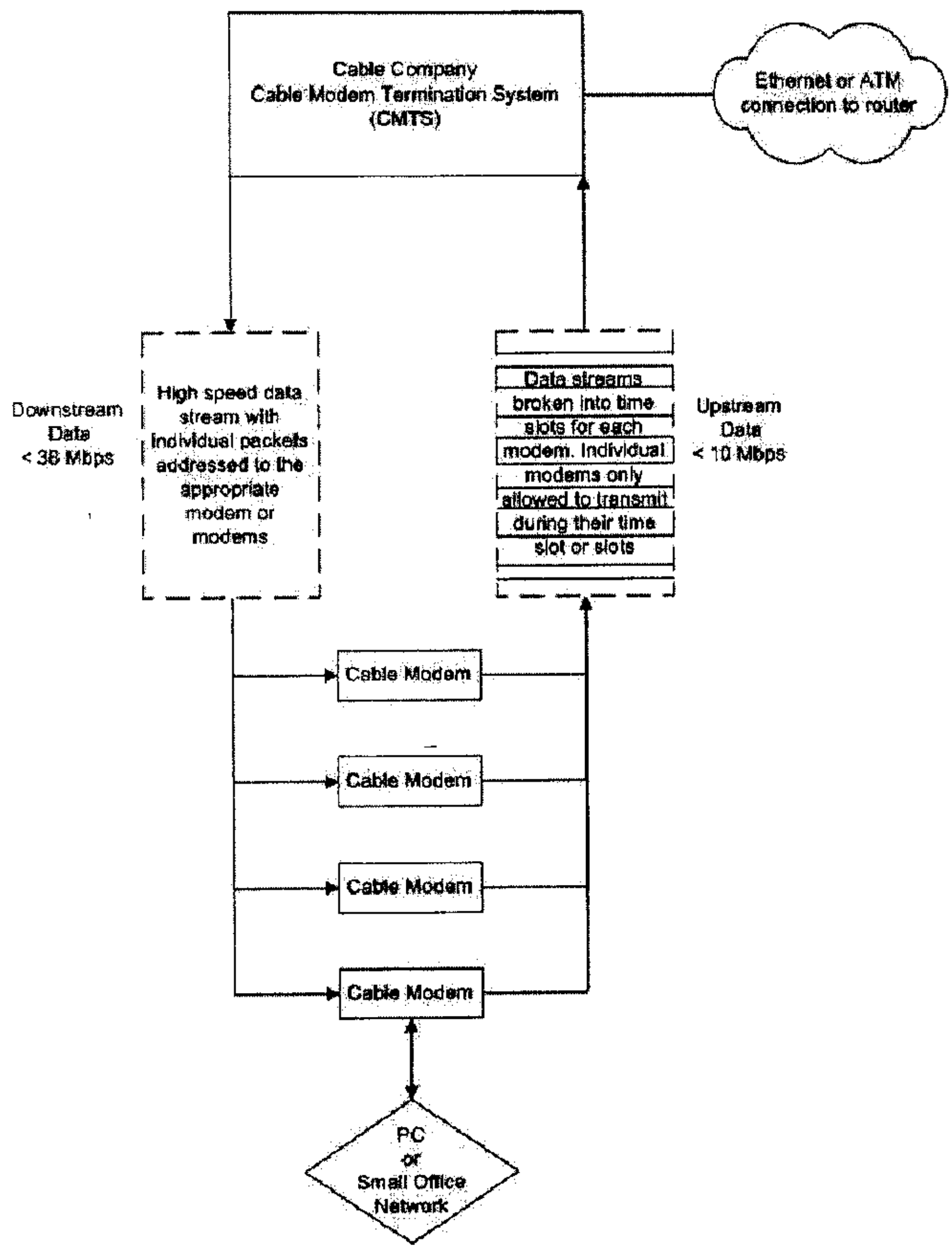
Operation of a Cable Modem Network

Cable modem network operation is comparable to Ethernet packet data networks, where many users utilize a shared medium. The modem is connected to the network by either the subscriber or an installer. Once on the network, the modem communicates with a cable modem termination system (CMTS), a device that sets the power level of the transmissions and assigns the modem one or more time slots for upstream transmission. All downstream data is sent out in one shared stream, with each modem reading only authorized information addressed to it. Upstream data is arranged into slots, where each modem "speaks" during its assigned time slots.[50] Business or high-end customers may receive more time slots or higher priority.

Cable modem transmission is illustrated in Figure D-3.

[50] "DOCSIS Cable Modem Technology." David Fellow and Doug Jones, *IEEE Magazine*, March 2001.

Figure D-3: Cable Modem Transmission



Digital video and phone services are offered on separate channels. As telephone technologies become integrated with Internet Protocol (IP), voice and video will be capable of being combined into the same channels as cable modem data. The same headend equipment, probably a CMTS, would serve as the headend interface device for all services.

The CMTS also interfaces RF cable plant with the cable operator's Ethernet or ATM packet data network. As is illustrated in Figure D-2, a router connects the CMTS to the

Internet backbone, to an associated ISP, or to servers for mail, the web, news, and chat. Various local servers may also connect to the router at the headend for caching of frequently viewed web sites. Other content sources include video servers for video-on-demand that handle subscriber requests for access to scheduled programs.

DOCSIS: Evolving Cable Modem Standards

The dominant industry standards that govern data transfers on cable networks are known as Data Over Cable Service Interface Specification (DOCSIS). DOCSIS was developed by the Multimedia Cable Network System, a coalition of the predominant members of the cable industry. DOCSIS 1.0 was originally prototyped in 1997 and approved by the International Telecommunication Union (ITU) in 1998.[51] The DOCSIS 1.0 specification supports downstream data rates from 27 Mbps to 36 Mbps and upstream rates from 320 kbps to 10Mbps.[52] Most operational cable modem systems in the United States are DOCSIS 1.0 compliant.

More than 30 vendors currently produce DOCSIS-1.0-compliant cable modem products. CableLabs, the research institute of the cable industry, certifies compliance with DOCSIS. In 1999, CableLabs, issued a new set of specifications known as DOCSIS 1.1. The new standards defined new functionality and enabled cable operators to provide guaranteed bandwidth or Quality of Service (QoS), for cable modem users. Key enhancements of DOCSIS 1.1 include QoS and packet fragmentation capabilities. DOCSIS 1.1 provides the bandwidth and latency guarantees for toll-quality voice, dedicated business-class data services, and multimedia applications across a shared cable modem access network. Under DOCSIS 1.1 tiered services can be more reliably delivered and modem-addressing is made less complicated.[53]

DOCSIS 1.1 is currently only in trial use. Full adoption of DOCSIS 1.1 involves a number of necessary steps, including: 1) development by cable companies of improved CMTS data transportation schemes; 2) fulfillment by ISPs of 1.1 specifications; and 3) efforts by cable modem vendors to produce products that will work with a DOCSIS 1.1 system.

Caching

An ISP may cache (store locally) the information that subscribers request from the Internet. Content caching may improve network performance. When a user on the network visits a web site, the web server downloads the site from the Internet and sends it to the user's cable modem and also saves a copy of the site in a cache. As the cache space fills up, the oldest site files on the disk are cleared as the newest files are saved. If a user requests a site while it is cached at the headend, the server can download the site

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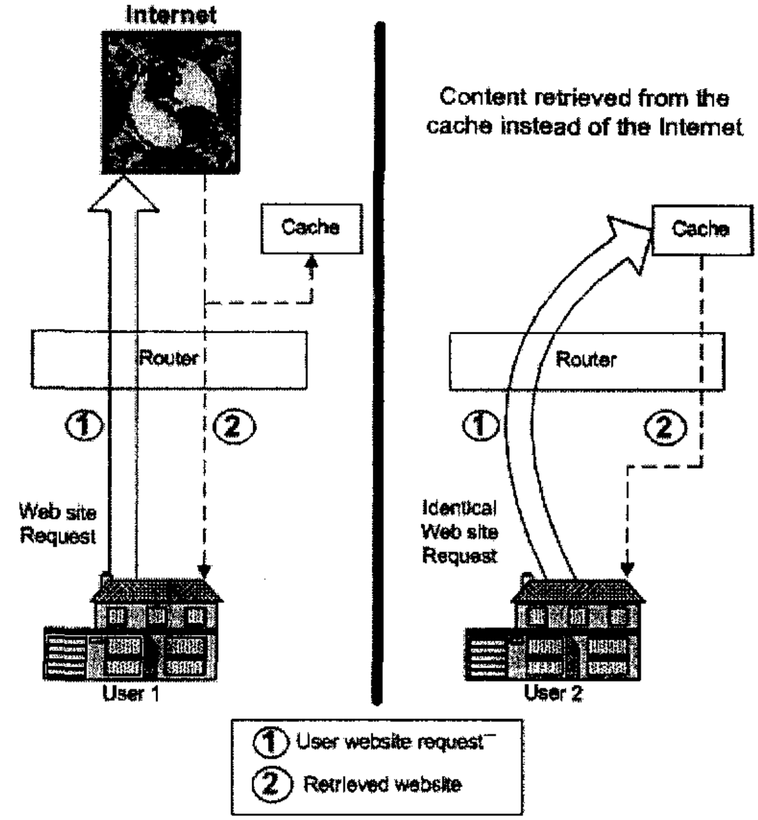
[51] "Cable Modem Standards and Specifications," http://cabledatacomnews.com/cmic/cmic3.html.
[52] "Key MCNS DOCSIS Technical Specs," http://www.cabledatacomnews.com/cmic/cmic3b.html.
[53] "DOCSIS 1.1 Sounds All-Aboard SIGNAL," Craig Kuhl, *Communications & Engineering Design*, October 2001, http://www.cedmagazine.com/ced/2001/1001/id1.htm.

directly from the cache to the user instead of using the Internet to access the web site again.

Multiple caches can be linked together to form cache hierarchies as well. If a site is not currently saved on a particular cache, the web server can try to retrieve the site from a cache at a regional ISP operations center, which is still faster than downloading from the Internet. This results in a faster download for the user and reduced traffic on the network.

Figure D-4 illustrates one use of caching. In this illustration, User 1 requests a site that is not currently cached, and the site is downloaded to the server cache as well as to the User. When User 2 requests the same site, it is obtained from the cache, eliminating the steps of going through the Internet to find and retrieve the site.

Figure D-4: Site Caching



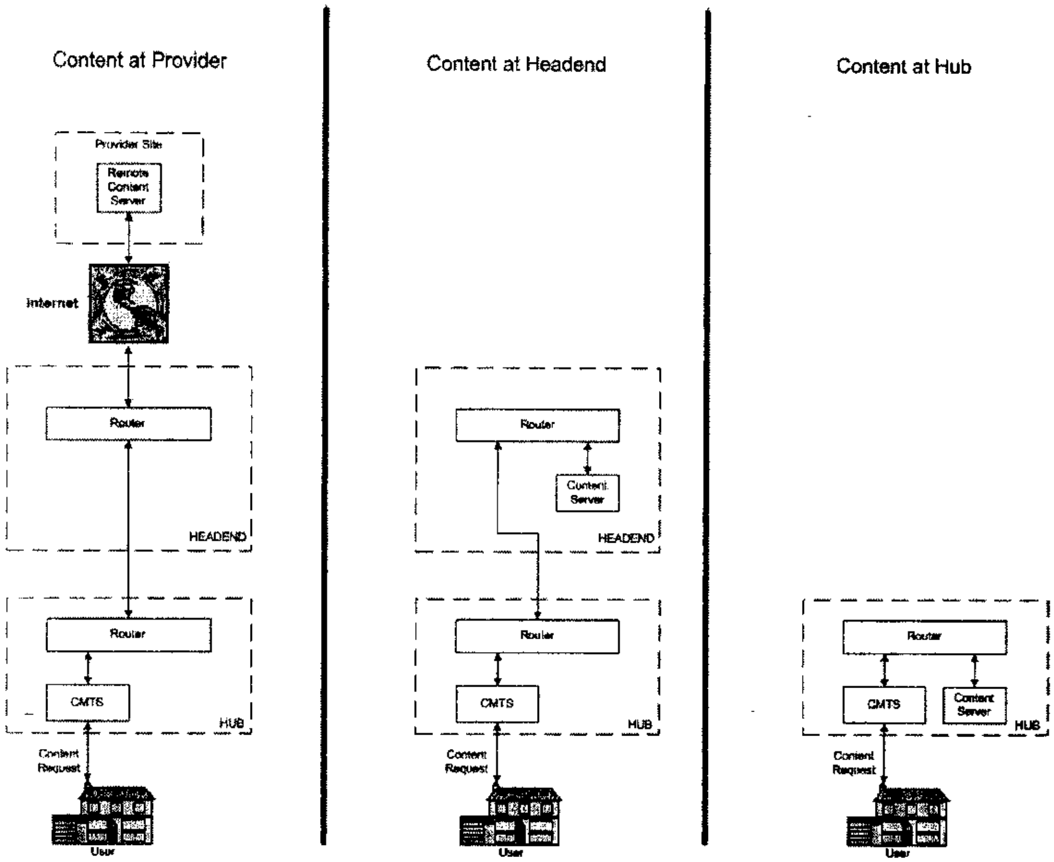
Locating Content Locally

Guaranteeing high quality video-on-demand and interactive services may require more extensive data and processing capability at the headend or regional network operations center (NOC) rather than a the facilities of the Internet content provider. In this scenario, content providers such as Intertainer.com, who supply live and stored video and interactive games, station their content sources and processing power at local headends or regional NOCs.

As with site caching, distributing and moving data closer to the subscriber can increase file access speed and reduce bandwidth consumption on the Internet backbone. A content server at the headend can deliver programming to users faster and more reliably than a remote content server across the public Internet. Delivering content from headend servers also reduces Internet traffic and network congestion.

A network of smaller servers throughout the Internet also increases redundancy and allows different geographic areas to have customized video availability. Three different content server placement scenarios are illustrated in Figure D-5.

Figure D-5: Locating Content Locally



II. Advantages and Limitations of HFC Architecture

The use of fiber optic cable in HFC systems provides a significant number of advantages over all-coaxial branch and tree systems. These improvements include:

- Fiber backbone with greater capacity than coaxial trunk cables.
- Ability to segment neighborhoods based on nodes, increasing available capacity for each subscriber.
- Reduction in active components, decreasing noise.
- Higher reliability and more cost effective maintenance.
- Fiber replacing much of the coaxial cables plant, reducing susceptibility to unwanted electromagnetic interference.

HFC systems have the potential to offer high-speed Internet service with hundreds of times the upload speed of conventional phone line services. In practice, properly operating cable modem networks operate about three times as fast as telephone services in the upstream direction and twenty-six times as fast in the downstream direction.[54] HFC capitalizes on the fact that the cable pipe is the largest bandwidth pipe into most residences and that cable architecture can be modified in a cost-effective manner to deliver packet-based data networking to customers. Effectively, all of the customers on a cable modem network are on one Ethernet-based local area network, as if they were in the same office building or campus. This is a great advantage for delivering fast download speeds to customers. Video-on-demand, subscription video-on-demand, and telephone services can also be offered over HFC networks.

HFC systems also offer significant reliability, as well as capability to monitor problems and outages, such that customer complaints are not the sole form of status monitoring, as they are in branch and tree systems. As the Internet becomes a more critical part of economic and emergency infrastructure, that reliability becomes crucial. Customers rely on the telephone infrastructure for critical services and will increasingly demand the same reliability from cable modem infrastructure for Internet and telephone services.

Significantly, HFC systems are capable of offering open access, as is described in detail below. AT&T is currently offering ISP choice on a trial basis on its HFC system in Boulder, Colorado. AT&T is reportedly planning to offer open access statewide in Massachusetts in 2002.[55]

The shared HFC architecture also creates limitations for the network. For example, security concerns necessitate that packets on the network be encrypted or scrambled to protect the information of subscribers sharing a segment. The architecture also does not offer a ready-made solution to offer a range of service levels to different customers. Finally, the network architecture makes it more difficult to separate the provider of the physical architecture from the provider of the Internet connection and Internet services, relative to a physical architecture where each user has a dedicated physical connection from a home or business to the ISP's routers. All of these challenges have solutions that are being tested and implemented in the cable industry.

Another limitation of the HFC architecture is that extensive additional fiber construction and terminal equipment are required to scale HFC systems for significantly greater bandwidth per customer. There exists a hard capacity limit per node area. The limitation is imposed by the need for data services to go through HFC-based router equipment in the cable headend. In all existing and planned cable modem systems, the hardware limits each network segment to 40 or less Mbps capacity. In order to increase the capacity available to a subscriber, the cable operator must segment its system to progressively smaller node areas. Even at maximum segmentation, HFC will have a hard limit of 40 Mbps per user. This is in contrast to fiber optic technologies, that transport hundreds of thousands of Mbps, and that can be easily scaled to higher speed as technology advances

[54] AT&T Broadband Welcome Letter, http://help.broadband.att.com/faqprintable.jsp?name=downstream_rate_management.

[55] "A Tale of Two Trials," Leslie Ellis, *Communications & Engineering Design*, May 2001, http://cedmagazine.com/ced/2001/0501/05d/htm.

by changing the equipment at the ends of the fiber and leaving the cable plant itself unchanged.

HFC-based equipment is also more specialized than equipment for fiber optic communications and is thus manufactured by fewer companies. This affords the cable operator less flexibility than an ISP using telephone or carrier facilities.

Appendix E: Technical Description of Fiber-to-the-Curb Architecture

The third category of systems, known as fiber-to-the-curb (FTTC), continues the trend of deploying fiber deep into the network. As nodes are segmented into smaller areas, the number of users on a node decreases and available bandwidth and system redundancy increase. In a variation of FTTC architecture, "fiber-to-the-home" (FTTH) systems deploy fiber all the way into residences. As of the current writing, there exist only a few FTTC systems in the United States, and the cable industry has not announced plans to upgrade most systems to this level.

The following section describes a network infrastructure that combines the physical architecture of existing FTTC systems, which has been deployed in a few communities, with an advanced headend and hub concept that incorporates existing, tried technologies, although it has not been deployed. This architecture represents the next generation of cable network construction because of its flexibility in providing either cable-based or fiber-based services, its capability to directly connect multiple service providers to subscribers, its operational robustness, and its almost unlimited capacity per subscriber. For these same reasons, this architecture serves as the basis for the model public interest architecture described in the body of the Report.

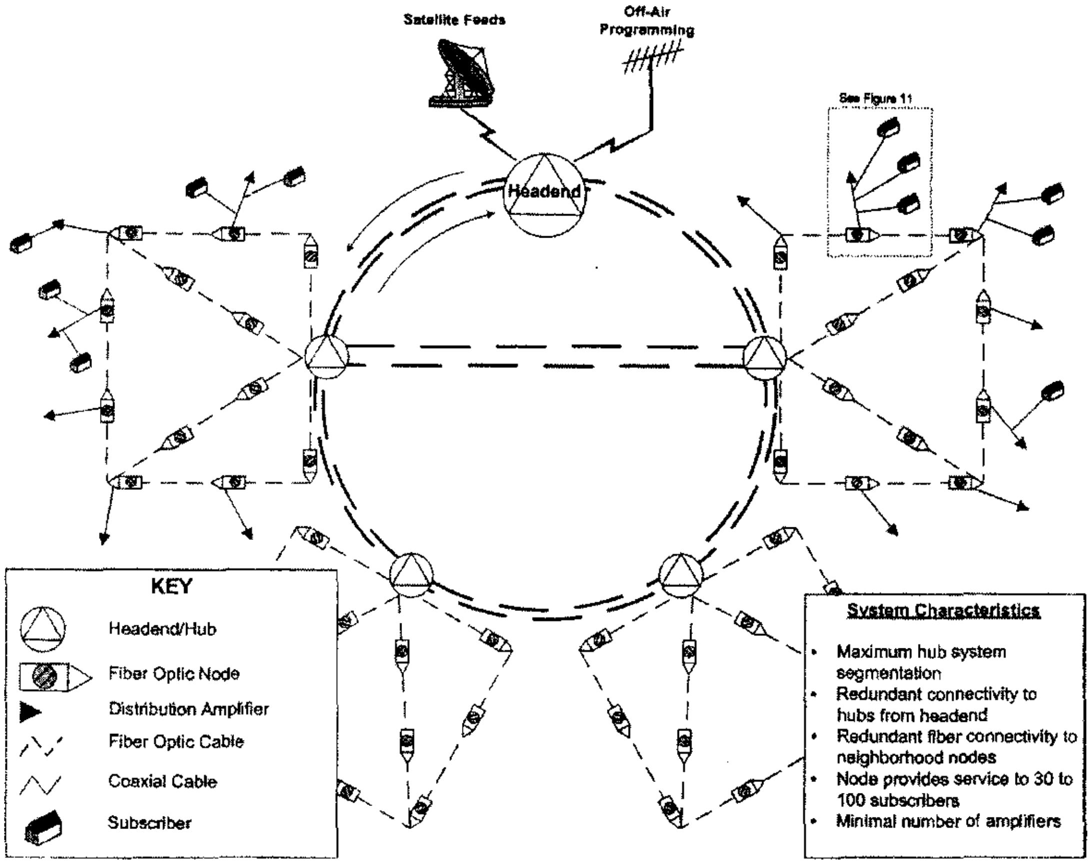
I. Technical Description of FTTC Architecture

FTTC systems can provide more advanced high-speed interactive services than do HFC systems. An FTTC system can simultaneously offer interactive television, video-on-demand, and higher capacity data and Internet access. The deployment of fiber optics deep into neighborhoods enables the provider to offer all of the applications possible in HFC systems, and to operate with increased reliability and redundancy.

FTTC architecture is characterized by headends and hubs interconnected with fiber in multiple rings. In addition, fiber rings extend to neighborhood nodes, with 10 to 150 homes per node. The fiber follows city and neighborhood streets past residences, with more than one transmission path to the headend or hub for each node. Redundant transmission paths ensure that loss of an interconnection cable at one location will not create a single point of failure. Although this discussion is specific to cable networks, FTTC principles are also applicable to a carrier who provides its services over twisted-pair telephone lines.

FTTC architecture is illustrated in Figure E-1.

Figure E-1: Fiber-to-the-Curb Architecture



As envisioned here, FTTC systems have sufficient capacity to offer individual subscribers a choice between, on the one hand, cable-modem based services for the home and small office, and, on the other hand, premium carrier-grade direct fiber optic services. Additional fiber optics enable a residential or business subscriber to obtain fiber optic connection at relatively low installation charge, providing the option of receiving higher speed symmetrical services on pipeline unmanaged by the cable operator. This is an attractive option for a user who requires high capacity. It may also be desirable for a customer who cannot send information through a shared cable modem system because of specialized applications, security needs, or a need to connect directly to a specific network.

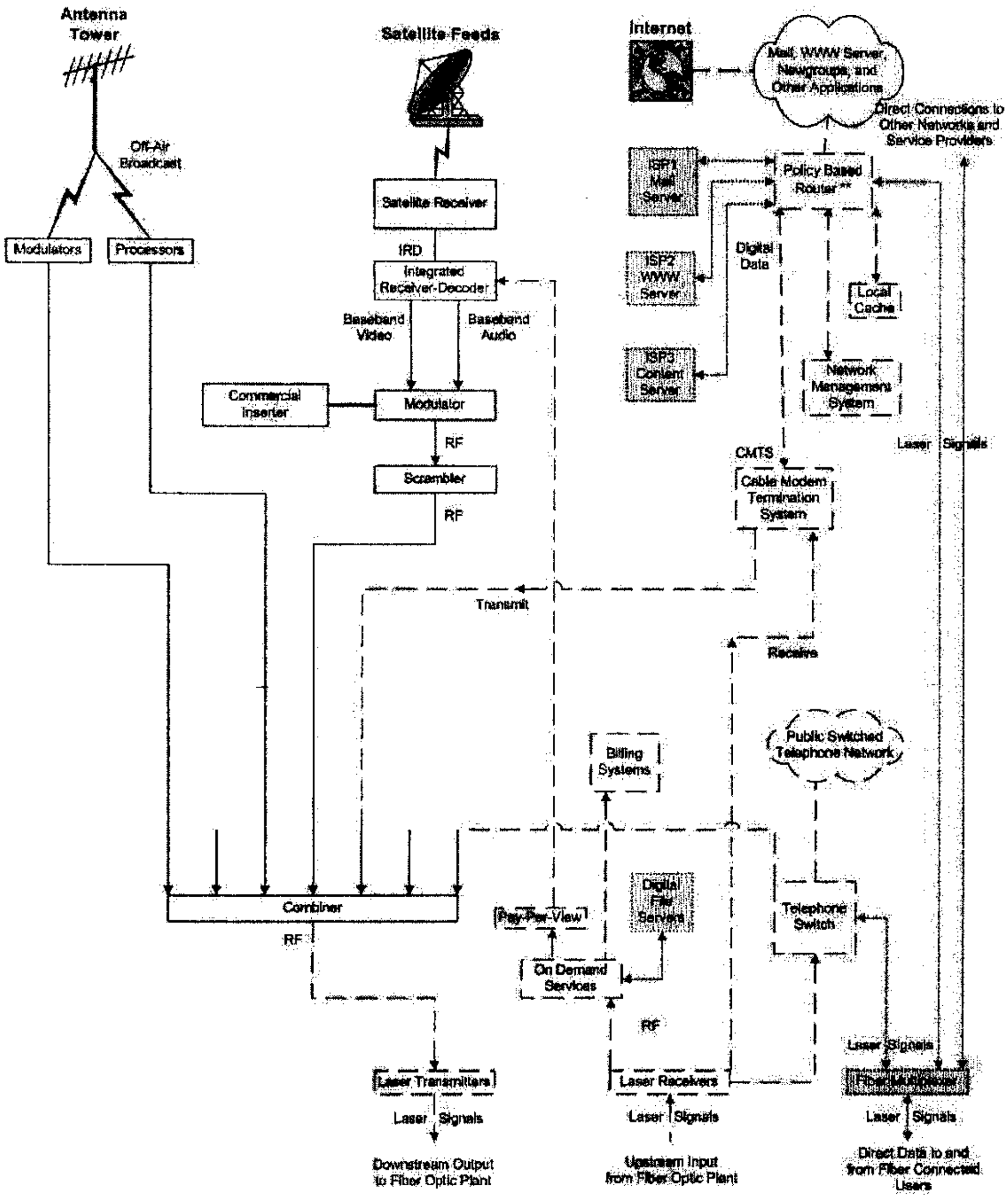
In addition to the equipment included in HFC headends, FTTC systems may include digital file servers for video-on-demand and interactive television services for video-on-demand subscribers. As more advanced and lifeline services are introduced on the system, more system monitoring equipment may need to be installed in the headend and in the physical plant.

Users desiring Gigabit Ethernet or other premium high-speed service will connect via fiber directly into the headend or hub router or SONET multiplexer, bypassing the CMTS equipment. This can be accomplished by offering direct fiber users a managed service in which they connect to cable company routers, or by offering users opportunity to connect to other service providers in a co-location area in the headend or hub.

Figure E-2 illustrates an FTTC headend or network operations center. FTTC headends include:

- SONET-based fiber multiplexer equipment for telephony and fiber customers.
- Packet switches and routers between customers and the Internet.
- Status monitoring of signal parameters and operation of field equipment.
- Remote monitoring of equipment, HVAC, and intrusion at hub sites.
- Cache servers.
- Co-location of facilities for multiple service providers.
- Servers for interactive television, video-on-demand, subscription video-on-demand, and web content (potentially multiple competing providers in the co-location area).
- Back-office infrastructure for subscriber and service provider provisioning and billing.
- Multiple survivable Tier 1 connections to the Internet from multiple providers.
- Staffing for 24 hours per day and seven days per week.

Figure E-2: Fiber-to-the-Curb Headend*



* Dotted lines and shaded boxes indicate components and services not present in an HFC system.

The few companies currently using FTTC include:

- 21st Century Communications (now RCN) in Skokie, Illinois.
- Bell South in Atlanta.
- Qwest Choice TV in Phoenix, Omaha, and Boulder.

The City of Palo Alto has a small, one-year, FTTH trial underway.[56] An FTTH system is planned in Grant County, Washington by the local Public Utility District. Reportedly,

When completed in 2005, the Zipp [Grand County] network will contain some 50,000 miles of fiber in its effort to reach 40,000 homes, businesses, and farms throughout Grant County. To date, the network passes about 7,000 homes with approximately 2,000 customers "lit" and receiving services.[57]

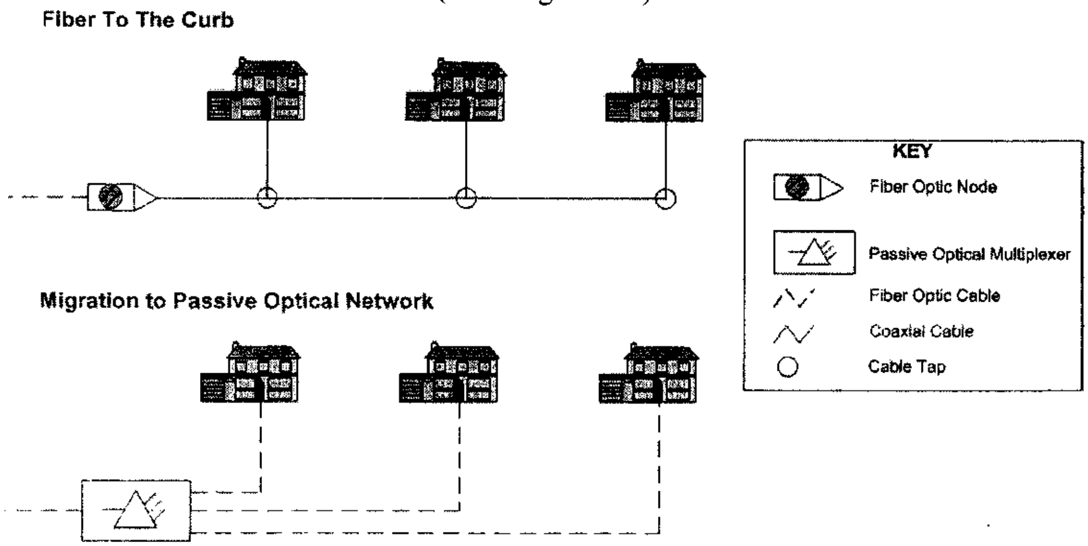
II. Advantages of FTTC Architecture

Once constructed, FTTC architecture more economically facilitates the construction of fiber directly to those subscribers who request additional bandwidth, such as businesses and residents who run home businesses, telecommute, or are early adopters of new technology. With the ability to connect individual users with dedicated fiber optics, capacity is almost unlimited. Reliability is increased by replacement of active electronic components and coaxial cables by temperature and RF resistant fiber optic networks. In addition, the subscribers are able to connect via a range of services, including 10/100/1000 Mbps Ethernet, ATM, and dedicated fiber optics known as "dark fiber."

Scalability is high with FTTC because of the high density of fibers and coverage of nodes. The system can be upgraded, in its entirety or by neighborhood, to a fully fiber-optic passive optical network (PON) by: 1) constructing fiber to users' homes, and 2) installing multiplexers at node locations, as shown in Figure E-3. Migration of FTTC to PON would not only eliminate the active components, but would also increase system scalability with almost unlimited capacity available to each home.

[56] Robert Pease, "Gauging the Future of FTTH," Lightwave, November 2001.
[57] Robert Pease, "Rural Washington county pioneers optical broadband services," Lightwave, February 2002.

Figure E-3: Migration from Fiber-to-the-Curb to Passive Optical Network
(from Figure E-1)



This model should be of interest to new cable operators and operators constructing networks in new developments, campuses, and apartment buildings because an FTTC system may be the optimal choice when building a new network. Its advantages include the following:

- Fiber optic cable costs approximately the same per-mile as coaxial cable.
- Either fiber optic or cheaper coaxial-based equipment can be used.
- The system addresses the limitations of HFC technology.

Appendix F: Summary Comparison of Three Types of Architecture

	Branch and Tree	Hybrid Fiber/Coaxial	Fiber-to-the-Curb
Capacity	330-550 MHz (45-80 TV channels)	750-860 MHz (80 analog TV channels, hundreds of digital video, music channels)	Same as HFC; effectively unlimited for direct fiber subscribers
	one-way	two-way	two-way
Typical phone capability per customer	None	1-2 phone lines*	Same as HFC; effectively unlimited for direct fiber subscribers
Typical data capacity per customer	None	128 kbps upstream, 1-2 Mbps downstream	Same as HFC; with option for direct fiber with 1000+ Mbps data, both ways
Digital TV capability	Yes	Yes	Yes
Number of active components in series	Up to 40 amplifiers	Up to 8 amplifiers	Up to 2 amplifiers; Direct fiber subscribers have no active components in outdoor cable plant
Backup power	At headend	At headend, hubs, and power supplies**	At headend, hubs, and power supplies**
Video-On-Demand capability	No	Yes***	Yes***
Redundant Architecture	• None	• Between headends and hubs	• Between headend and hubs • For all fiber in system

* Depends on powering and degree of redundancy in network

** Depending on architecture, subscribers receiving telephone service may have backup power at subscriber premises

*** Depending on capability of servers at headend or hub and the number of simultaneous users of the service